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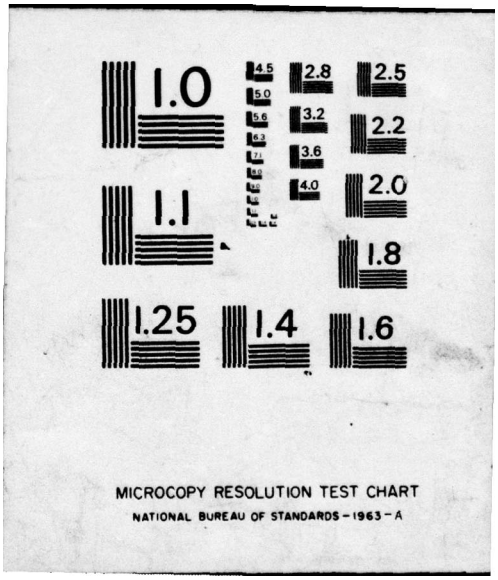
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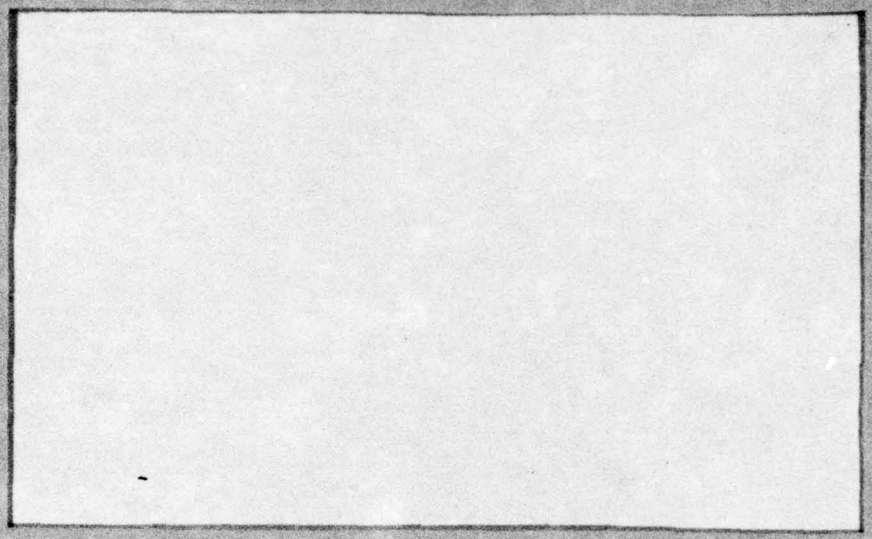

NEW YORK UNIVERSITY
FACULTY OF ARTS AND SCIENCE
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Computer Graphics and Image Processing

FINAL REPORT

for

Contract N00014-75-C-0572

Herbert Freeman
Principal Investigator

Prepared for

Office of Naval Research, Code 437
Information Systems Program
Department of the Navy
Arlington, VA 22217

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ABSTRACT

This is a final report on contract N00014-75-C-0572 and describes the research performed under the contract during the period 1 June 1969 - 31 December 1975. The research had as its objective the development of effective computer techniques for analyzing and manipulating line-drawing data with a digital computer. The specific research activities carried out under the contract are summarized in terms of abstracts of technical reports and journal articles.

TABLE OF CONTENTS

I. INTRODUCTION

This report represents the final report on Contract N00014-75-C-0572 (and its predecessor N00014-67-A-0467-0010) and covers the period 1 June 1969 through 31 December 1975.

The research was broadly directed toward developing improved techniques for processing line-drawing data with a digital computer. Specific investigations carried out under the contract were concerned with (1) the smoothing, filtering and matching of chain-encoded line-drawing data, (2) the generation of moving-picture sequences with a digital computer, (3) the on-line pattern recognition of hand-drawn symbols, (4) the development of an extensible computer language for graphic-data processing, (5) the development of algorithms for the high-speed description of curves and surfaces, (6) the efficient layout of templates on stock sheets, and (7) the high-level programming of mechanism motion.

The results of the research efforts have been published in a series of 11 technical reports and 5 journal articles. Three doctoral dissertations have resulted from the work (Sharma, Reggiori and Spegel). It is anticipated that some additional journal articles based on work performed under the contract will still appear during the coming year.

II. ABSTRACTS OF PUBLICATIONS

The following pages contain the abstracts of all the publications issued under the contract. The abstracts are grouped by technical reports (A) and journal articles (B). Within each group, the items are arranged in chronological order.

For each publication, the name of the author is given, as well as the title of the report or article, and either the NYU technical report number or the journal in which the article appeared. Also included is the Accession Number with which the item may be obtained from either the Defense Documentation Center (DDC) or the National Technical Information System (NTIS).

A.1 J. Meltzer, "Computer Animation: A Literature Survey", Tech. Rept. 403-8, October 1969, (AD 696 989)

ABSTRACT

This report is a literature survey of works dealing expressly with computer animation. The papers are divided into the areas of general discussions, animation languages, and specific applications.

A.2 Onkar P. Sharma, "A Syntactic Model for On-Line, Real-Time Description, Analysis and Generation of Hand-Drawn Patterns", Tech. Rept. 403-12, May 1970, (AD 714 526)

ABSTRACT

Various concepts from language theory are extended to describe and analyze two-dimensional patterns. Emphasis is placed on the development of a flexible descriptive metalanguage and a compatible table-driven analyzer. A further generalization of syntactic models is made by the inclusion of time in the syntax specification. This permits syntax-directed analysis of on-line, handdrawn, two-dimensional patterns and automatic syntax specification for different classes of finite pattern sets. A description of a unidirectional, table-driven analyzer for checking the syntax is also included.

A.3 Onkar P. Sharma, "A Trainable Syntactic Model for Syntax Specification and Recognition of Hand-Drawn Two-Dimensional Patterns", Tech. Rept. 403-16, January 1971, (AD 723 236)

ABSTRACT

In order to make direct graphic input possible, which provides a most natural interface between a user and a computer, suitable pattern recognition schemes become essential. Schemes that employ feature extraction for recognition are almost invariably problem-oriented and thus lack generality. This dissertation presents the details of a syntactic model for on-line, real-time recognition of handdrawn two-dimensional patterns. The proposed model can handle different classes of patterns in a uniform manner.

Theory and algorithms of a grammar-building system are presented. The derivations in this grammar are time dependent. The input to the system is a complete specification of each pattern the user wants to have recognized, and the output from the system is a finite grammar that represents the specified pattern set. The system can thus be trained to adapt to the user's individual style of drawing, which is reflected in both the input and the output.

The details of a table-driven analyzer are described. The analyzer is extremely fast since the parsing is unidirectional. This has been made possible by imposing certain restrictions on the grammar generated by the system. Inclusion of a third variable-- time-- in the syntax specification further speeds up the recognition process by allowing concurrent inputting and analysis.

A.4 Giovanni B.Reggiori, "Digital Computer Transformations for Irregular Line Drawings", Tech. Rept. 403-22, April 1972, (AD 745 015)

ABSTRACT

An irregular line drawing is an abstraction of an image which can be defined as a set of planar curved arcs. The geometric features of these arcs are implicitly defined in the output of the preprocessing operations which generated the drawing from the image.

In order to process such a drawing with a digital computer, it is necessary first to describe it to the machine in a suitable language. Such a description is complete if and only if it includes all the desired features of the drawing. The precision of a complete description is then related to the precision with which each of the preprocessed features is represented in it. To represent a feature means essentially to substitute for it a feature for which a standard machine description already exists. Therefore, the quality of a description of a preprocessed irregular line drawing is completely determined by the resolution of the quantization scheme used.

Many quantization schemes have been studied in the past. In these schemes, the resolution is chosen independently from the type of processing to be done later on the quantized drawing. For example a particular resolution may be chosen because the user wants the quantized version of a curved arc to appear to him as smooth as the arc itself.

No mention exists in the current literature of the more general problem of choosing the resolution of the quantization scheme so that the quality of the quantized drawing after processing is satisfactory in some

specified sense. This thesis describes an approach to the solution of this problem when the required processing is a coordinate transformation. A general purpose quantization scheme is presented in a parametric form. Different quantized versions of the same drawing can then be obtained by changing the values of the parameters governing the quantization scheme. An optimal encoding scheme is described which utilizes the patterns in the quantized drawing.

Three figures of noise are introduced for describing three different aspects of the quality of the qunatization scheme. The first figure of noise is related to the average area between the quantized version of the drawing and the drawing itself. It also provides an indication of the difference between the length of the drawing and that of its quantized version. A second figure of noise describes the average maximum displacement between the quantized version of the drawing and the drawing itself. A third figure of noise serves as a measure of the so-called staircase effect. It should be noted that although many references to the staircase effect can be found in the literature, there has been no known scheme for quantifying it.

A figure of cost is presented for evaluating how much "cost" has been expended in transforming the quantized version of a given drawing.

A figure of merit is defined to indicate how much has been spent (figure of cost) for achieving the given quality (figure of noise) after transformation.

The effect of a coordinate-transformation on the three figures of noise is evaluated together with the non-reversible contribution due to the requantization following the transformation.

The thesis concludes with a comparison between the proposed quantization scheme and other schemes on the basis of their figures of merit. Bounds on the distortions in angle and length occurring when the drawings are quantized accordingly to a variety of quantization schemes are derived.

A.5 Hamid Rafii, "Implementation of EX.GRAF", Tech. Rept. 403-28, December 1972, (AD 757 069).

ABSTRACT

This report describes the implementation of a simple version of EX.GRAF (the Extensible Language Including Graphical Operations) on the Adage AGT 30 computer, and describes the approach as well as the results obtained so far. Much of the report is concerned with the description of the routines, which, as run-time routines, will implement different features of the language.

A.6 Marjan Spegel, "Linguistic Processing of Motion. A Survey", Tech. Rept. 403-32, May 1973, (AD 764 116).

ABSTRACT

The notion of linguistic processing of motion is introducted in this report. It is defined as the structural analysis and synthesis of motions and their representations by a computer. The motions are regarded as being composed of simpler, eventually primitive, motions called terminals. The basic concepts of programming languages are extended into the domain of computer-oriented description of motions. The concepts of formal language theory are shown to be pertinent to and useful for the formal treatment of motions. In particular, the linguistic processing of motion is suggested as an extension of linguistic picture processing into the domain of time.

The report consists of two parts. In the first the problem of linquistic processing of motion is defined and an overall approach for its solution is outlined. In the second, a survey of the relevant literature is given.

A.7 Hamid Rafii, "EX.GRAF 1 - A New Version of the Language EX.GRAF", Tech. Rept. CRL-35, December 1973, (AD 776 250).

ABSTRACT

This report describes a new extensible computer language intended primarily for graphical-data processing - EX.GRAF 1. The language can be regarded as an improved version of EX.GRAF, which was previously developed. The report describes the characteristics of the language, the general syntax and the provisions for extension, and illustrates the capability of the language by means of some simple programming examples.

A.8 George Chaikin, "Geometric Description and Generation of Surfaces", Tech. Rept. CRL-38, January 1975.

ABSTRACT

A geometric technique for the description and generation of arbitrary doubly-curved surfaces is given. The technique is based on a curve generating algorithm derived from Bezier and the author, which is described. A surface is then determined to be the set of surface curves defined by a set of generator curves. Finally, some features of surfaces of this type are examined.

A.9 H. Freeman, "On the Template-Layout Problem", Tech. Rept. CRL-39, February 1975. (AD-A023 170)

ABSTRACT

A challenging problem in geometric pattern fitting and graphic-data manipulation is that of packing as many copies of a given irregularly-shaped planar template into a large stock sheet of finite dimensions. The problem has many industrial applications, e.g., in sheet metal stamping and cloth cutting. This report describes a heuristic approach in which edge profiles are computed from the chain-code representations of the given templates. The edge profiles then facilitate the pairwise fitting of templates into modules which can be placed iteratively over the entire sheet, except near the boundaries where there may be insufficient space. Separate boundary modules are then utilized at the sheet boundaries. Three criteria for evaluating a pairwise template fit are described and related to the overall objective of achieving a maximum ratio of utilized to available space.

A.10 Margaret E. Kepner, "Synthesis, A Program for Generating Pictures", Tech. Rept. CRL-41, July 1975, (AD A016 653).

ABSTRACT

SYNTHESIS, an experimental program for the generation of pictures based on linguistic models, is described. This program allows a user to specify a picture grammar interactively and to display the associated picture elements. The program execution and organization are explained, and the data structure is presented. Some of the strengths and weaknesses of SYNTHESIS are discussed and directions of possible expansion are suggested.

A.11 M. Spegel, "Programming of Mechanism Motion", Tech. Rept. CRL-43 November 1975. (AD-A023 171)

ABSTRACT

This thesis develops the foundation for a high-level motion description language called MDL. It provides data types and operations with which the motions of mechanisms can be conveniently expressed.

It is shown how tree-structured, massless mechanisms can be constructed from a set of planar primitives. The world of moving mechanisms is represented by the scene. The mechanisms of the scene may kinematically interact with other mechanisms.

A scheme is introduced for expressing the set joint movements of a mechanism in terms of sequences of joint-variable increments called actions and treated as data types. In action expressions, primitive and non-primitive actions are combined into new actions by generalized arithmetic operators as well as by sequential and parallel composition. Motions occur when actions are imposed on mechanisms. Structured descriptions of actions and motions are thus made possible.

Facilities for the description and computation of constrained motions are introduced. They are based on the decomposition of mechanisms into kinematic chains and kinematic webs. A method for the "natural" distribution of motion along kinematic chains and webs is presented.

B.1 H. Freeman, "Interactive Computer Graphics - A Status Report", Proceedings of the VIth Yugoslav International Symposium, on Information Processing, Bled, Yugoslavia, October 1970, 1-16.

ABSTRACT

In tracing out the history of computers we find that computers were first designed to be applied to the solution of well-formulated mathematical problems. These were problems for which the method of solution was known but for which the execution of the calculations was either overly tedious or of such a magnitude as to be beyond the capabilities of human labor. These were problems for which algorithms existed; that is, one could find concise, unambiguous procedures that would yield the desired solution in a finite time. As our understanding of the workings of computers increased, we realized that we could apply computers also to problems for which no precisely defined, unique procedures existed. We called the techniques that were employed for these problems heuristics to distinguish them for algorithms. The study of heuristic procedures is today loosely classified under the title of artificial intelligence, and includes such topics as pattern recognition, theorem proving, economic system modelling, and chess playing.

B.2 Onkar P. Sharma, "A Specification System for Patterns", Journal of the Franklin Institute, 295, (1), January 1973, 39-58.

ABSTRACT

This paper is concerned with the development of a system that generates a finite grammar for a set of hand-drawn patterns. The input to the system is a set of description vectors which reflect the user's individual style of drawing the patterns of the set, and its output is a finite grammar that represents the specified set. Time is included as a third variable in the syntax specification; this allows concurrent inputting and analysis of patterns, thereby speeding up the recognition.

B.3 George Merrill Chaikin, "An Algorithm for High-Speed Curve Generation", Computer Graphics & Image Processing, 3, 1974, 346-449.

ABSTRACT

A fast algorithm for the generation of arbitrary curves is described. The algorithm is recursive, using only integer addition, one-bit right shifts, complementation and comparisons, and produces a sequential list of raster points which constitute the curve. The curve consists of concatenated segments, where each segment is smooth and open. The curve may be arbitrarily complex, that is, it may be smooth or discontinuous, and it may be open, closed, or self intersecting.

Implementation of the algorithm in a hardware microprocessor is considered as an extension to incremental plotting devices and other numerically controlled machines.

An extension of the algorithm to generate 3-D curves is described, along with techniques for their application to surface representation, nonlinear interpolation, and direction of numerically controlled milling machines and similar devices.

B.4 Herbert Freeman, "Computer Processing of Line-Drawing Images", Computing Surveys, Vol. 6, No. 1, March 1974, pp. 57-97.

ABSTRACT

This paper describes various forms of line drawing representation, compares different schemes of quantization, and reviews the manner in which a line drawing can be extracted from a tracing or a photographic image. The subjective aspects of a line drawing are examined. Different encoding schemes are compared with emphasis on the so-called chain code which is convenient for highly irregular line drawings. The properties of chain-coded line drawings are derived, and algorithms are developed for analyzing line drawings to determine various geometric features. Procedures are described for rotating, expanding, and smoothing line structures, and for establishing the degree of similarity between two contours by a correlation technique. Three applications are described in detail; automatic assembly of jigsaw puzzles, map matching, and optimum two-dimensional template layout.

B.5 Herbert Freeman, "On the Packing of Arbitrary-Shaped Templates", Proceedings of the Second USA-Japan Computer Conference Session, August 1975, 102-107.

ABSTRACT

A challenging problem in geometric pattern fitting and graphic-data manipulation is that of packing as many copies as possible of a given irregularly-shaped planar template into a large stock sheet of finite dimensions. The problem has many industrial applications, e.g., in sheet metal stamping and cloth cutting. This paper describes a heuristic approach in which edge profiles are computed from the chain-code representations of the given templates. The edge profiles then facilitate the pairwise fitting of templates into modules which can be placed iteratively over the entire sheet, except near the boundaries where there may be insufficient space. Separate boundary modules are then utilized at the sheet boundaries. Three criteria for evaluating a pairwise template fit are described and related to the overall objective of achieving a maximum ratio of utilized to available space.

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